EC MICROBIOLOGY
Perspective

The Era of Nanotechnology - An Opportunity to Benefit from Novel Antimicrobial Solutions

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Pathogens have constantly and persistently evolved through the millennia to sense, respond to, and survive the most sophisticated natural and artificial challenges that they encounter. Scientific advances have, occasionally, led to innovative antimicrobial compound developments that have helped to eradicate certain important diseases. Clever design and sometimes pure fortune have led to the discovery of revolutionary compounds, like penicillin, that have significantly tilted the balance in the fight against major microbial pathogen's towards humanity's favor.

In the meantime, natural selection has worked in favor of the pathogen, providing the basis for the development of antibiotic resistance. It is not uncommon for the international news to be overwhelmed with information about new "superbug" strains resistant to antibiotics and capable of causing severe disease [1,2]. The high importance of this issue can be illustrated by the recent pledge of Heads of State at the United Nations to coordinate efforts in order to limit the spread of antimicrobial resistance infections [1].

A close analysis of the facts indicates that the most possible reason underlying the global rise in antimicrobial resistance is our inefficiency in discovering not only new antibacterial drugs but also drugs that will overcome natural selection in microbial populations. It is true that scientific advances have led to a much great understanding of the mode of action of many important antibiotics; however, it has failed to provide long lasting solutions in most fields. It is now a general admission that our arsenal against microbes is rapidly diminishing [3,4].

Despite this drawback, it is the emergence of new scientific areas of research that may hold the key to the development of novel antimicrobial treatments. The term "nanotechnology" corresponds to the ability to image, manipulate and model functionalities on the nanometre scale [5]. Nanotechnology is characterised by the use of "nanoparticles" which are defined as particles of a size less than 100 nm [5]. Our increasingly precise technical ability to design biologically active nanoparticles may indeed provide novel antimicrobial solutions to aid the prevention, diagnosis and treatment of new and existing microbial pathogens [6-16].

Meanwhile, the coordinated effort of researchers across the globe has led to the identification of new microbial strains that live inside and on us (the microbiota) [17]. Remarkably, the human microbiota outnumbers our somatic and germ cells by approximately 10-fold. The microbiota combined genomes is defined as the "microbiome" [17]. The Unified Microbiome Initiative aims to provide the tools that will eventually facilitate our understanding of not only the microbiome of humans, but also those of other animals, plants, the earth, the ocean, and the atmosphere [18,19].

It is, therefore, a combination of major nanotechnological advances together with the identification and understanding of how microbial populations exist inside or outside the human body that is likely to provide antimicrobial breakthroughs in the future.

A good example of antimicrobial nanoscience is the application of silver nanoparticles as antimicrobials in wound dressings to treat wound injuries [14,20,21]. Silver nanoparticles have also been used as coatings for consumer products and biomedical devices [20,22].

Indeed hydrogel containing silver nanoparticles displayed better antibacterial activity and wound-healing capability, preserving normal skin appearance and hair growth when compared to the normal cream without nanoconstituents [22].

Another popular example involves the recently identified graphene [23]. Graphene has unique physicochemical properties including a wide surface area, exceptional electrical and thermal conductivity, and outstanding biocompatibility [23,24]. This latest property has increased the use of graphene oxide as an antibacterial agent recently employed in the treatment of infections displaying multidrug resistance [24,25]. To further enhance the uses of graphene oxide as an antimicrobial agent, a number of nanocomposite structures have been developed [24]. These include different surface modifications and functionalisation with inorganic nanostructures, including biomolecules and polymers in order to improve its antimicrobial properties [24,26,27].

One, of course, has to consider the human and environmental side-effects of a rapidly growing nano-industry and the potential ecological effects of an exponential increase in the release of engineered nanomaterials in a worldwide scale [28]. Recent research has investigated the toxicity of ingested nanoparticles and concludes that these structures are unlikely to display toxic effects at typical levels of human exposure [29]. It is true, however, that as with all new technologies, very careful and well-documented research is needed to characterise possible more subtle or chronic effects [28-30]. The necessity for further investigation is highlighted with respect to intestinal permeability or oxidative stress, and also the ability of new nanotechnology to affect host-gut microbial balance [29].

There are wonderful prospects for nanoscience to significantly contribute to our efforts in deciphering complex microbiome systems and understanding how versatile microbial populations use natural selection to develop antimicrobial resistance. Creating the capability to image, sense, and stimulate at the scale of microbial dimensions is paramount in strengthening our efforts to eavesdrop, understand and, ultimately, manipulate the microbiome [18]. This is graphically depicted in the figure below (Figure 1). In view of the current stagnation in the development of new antimicrobial drugs, it is widely accepted that new technologies, including nanotechnology, may input positively in our quest against pathogenic microbes and the global eradication of disease.

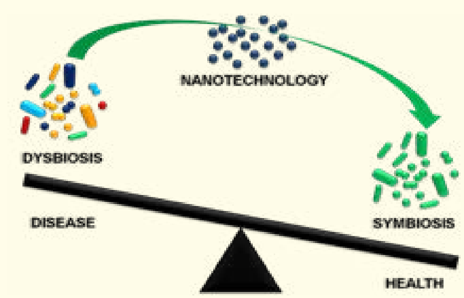

Figure 1: *Graphical illustration highlighting the importance of nanotechnology in combating dysbiosis and disease. Correct use of nanoscience will strengthen its role in tipping the balance towards microbiome symbiosis and health.*

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